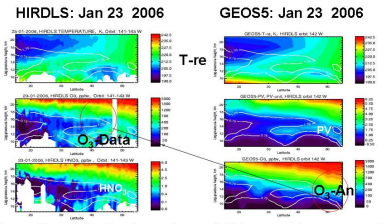
# Forecast and Analysis of Vertical Ozone Structures in the UTLS: Scale-Dependent Assimilation Schemes of Multi-Instrumental Data

V. A Yudin (vyudin@ucar.edu), J.C. Gille, J.-F. Lamarque, D.E. Kinnison, B. Nardi, R. Khosravi and S. I. Karol

NCAR/ACD, POB 3000, Boulder, Colorado, USA

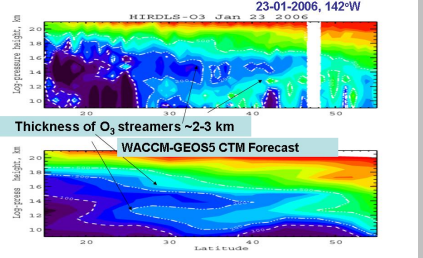
***Abstract.*** *The paper evaluates forecasts and analyses of vertical ozone ($O_3$) structures in the Upper Troposphere and Lower Stratosphere (UTLS). The study was motivated by ability of HIRDLS (High Resolution Dynamics Limb Sounder) instrument to observe thin vertical layers of constituents ($O_3$ and $HNO_3$) and failures to mark these layers in the $O_3$ analyses. The shortcomings of analyses can be related with the inadequate treatment of vertical resolution of space-borne data (SBUV) by assimilation schemes. To overcome this problem the class of so-called scale-dependent assimilation schemes is introduced for joint analysis of data characterized by different vertical resolutions. These schemes preserve the observed thin layered structures (2-4 km) of ozone when column-based data are assimilated. For the multi-year climate studies paper discusses the adequate representation of vertical structures of analyzed $O_3$ and $H_2O$ using HIRDLS and MLS data (2004-2008) in the equatorial stratosphere.*

## Motivation by Aura orbital plots: HIRDLS vs GEOS5 in the UTLS

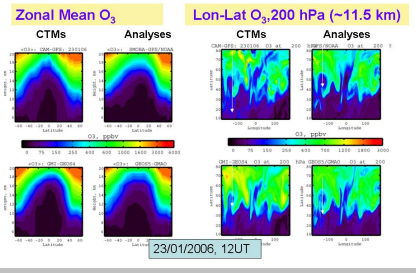



*How often and why $O_3$ analyses fail to reproduce ozone thin layers characterized by negative vertical gradients of $O_3$?*

## HIRDLS $O_3$ data and CTM $O_3$ forecast (comparable scales in the data analysis, $\delta h/\delta z$ ~N/f)

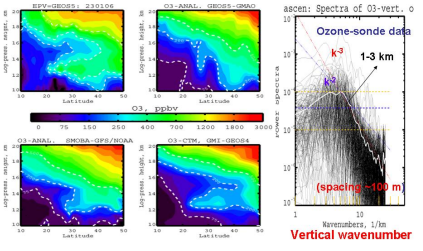



## $O_3$: CTMs (CAM-GFS & GMI-GEOS4) and Analyses (NOAA-SMOBA and GMAO-GEOS5)

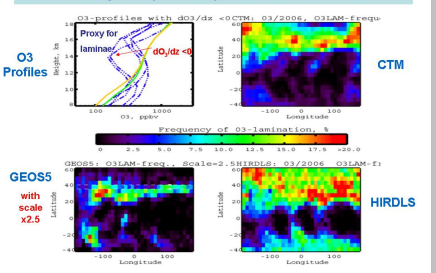



## PV and $O_3$ Analyses and CTM, 142ºW, 23/01/2006, 12 UT

## Spectra vertical oscillations of $O_3$




## Lamination frequency reproduced by CTM, Analyses (GEOS5) and HIRDLS retrievals




## Consistent resolutions of observing systems: models and observations *(Fox-Rabinovitz & Lindzen, 1993)*

***desirable $\delta z_c$ ~N/f$\delta$h for the extra-tropical UTLS***

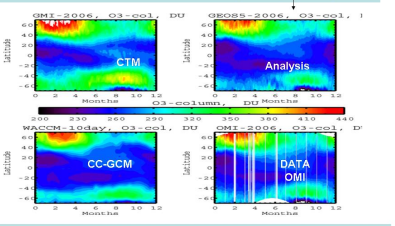
**Analyses/Models, $N_X x N_Y x N_Z$**

- GMAO/GEOS-5.1.0 540x360x72
  $\delta z_c$ ~250m vs $\delta z_m$~1 km
- NOAA/GFS-SMOBA 360x180x36
  $\delta z_c$~ 500m vs $\delta z_m$~1 km
- GMI-CTM-GEOS4 144x 91x45
- CAM-Chem-GFS 144x 96x28
  $\delta z_c$~ 1 km vs $\delta z_m$~1 km
- WACCM3-SST/QBO 72x 45x76
  $\delta z_c$~ 2 km vs $\delta z_m$~2 km
- WACCM3-CTM-GEOS5 180x 91x72
- WACCM3-CTM-with DAS
  $\delta z_c$~ 1 km vs $\delta z_m$~1 km

**Types of $O_3$ data**

- *Type-1:* **Column-based $O_3$ data** (OMI, TOMS, SBUV)
- *Type-2:* **Vertical profiles** (limb instruments HIRDLS, MLS, MIPAS with $\delta z$ ~ N/f $\delta$h constrain dynamics)
- *Type-3:* **Smoothed profiles** (nadir sensors => layer-averaged data AIRS, TES, METOP…. with $\delta h/\delta z$~ $\delta h$/Hp ~1-5 =/= N/f)
- *Type-4:* **in-situ vertical profile data** (no horizontal sampling sondes, SHADOZ and WOUDC)

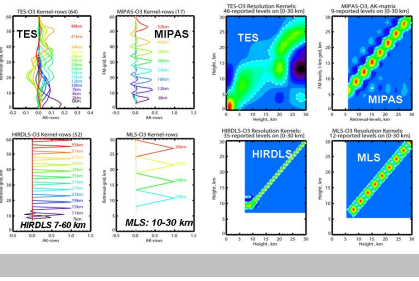
## Type I Data: Comparing $O_3$-colums (DU): CTM, WACCM-climate, GEOS5 (2006),OMI (2006)



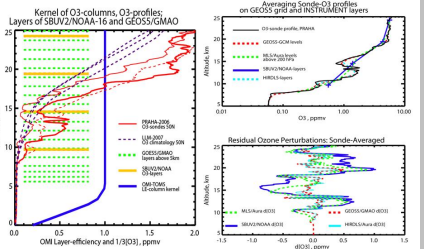

*OMI O3-columns are reproduced by models and analysis*

## Types II-III: Characterization of $O_3$ profiles by Resolution Kernel matrices: Rows and Images

(Averaging, *Sharpness, Symmetry, Values and Properties*)



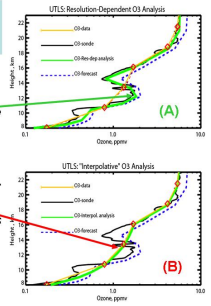

## Data/Instrument and Analysis/Model grids: *resolved (visible) and invisible (Nyquist) scales*



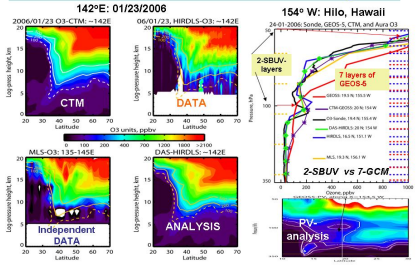

## Resolution-dependent analyses schemes

- A) *Preserving vertical $O_3$ short-wave components by resolution-dependent scheme that adjust only "visible" scales.*
- B) *Treating "layer-averaged" data as a "point-wise" data => "backward" interpolation from the data space to the analysis grid*

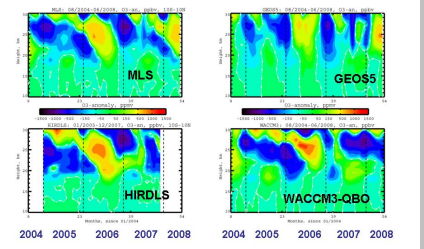
***Compare the (A)- and (B)- "green" analysis curves***



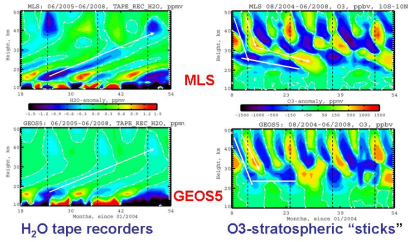

## Examples: Assimilating LS intrusions in UT with vertical resolution of HIRDLS-$O_3$




## Equatorial $O_3$-anomaly (10ºS-10ºN, 2004-2008): data, analysis, and model simulations




## Equator: $H_2O$ and $O_3$ stratospheric analyses GEOS5 and MLS (HIRDLS-$H_2O$, future data versions)




## Conclusions

- *Nadir sensors with $\delta h/\delta z$ ~1-5 << N/f ($\delta z$ ~$H_p$)* report the smoothed profiles that are still column-based data.
- *Limb sensors deliver profile-based data with $\delta h/\delta z$ ~ N/f* consistent with model dynamics and monitoring transport of ozone in thin layers of the UTLS (*MLS and HIRDLS*).
- To advance multi-instrumental $O_3$ products (analyses, retrievals) along with characterization of data by resolution kernels the *scale-dependent assimilation schemes should be developed.* Erroneous treatment of column-based measurements as the point-wise data may degrade analyzed fields.
- ***Message for Assimilation**: Don't blend incomparable vertical scales of observations and forecasts, constrain only scales visible to the instrument, preserving short-scale structures of models.*

- ***Acknowledgements to*** Aura Instrument Science Teams, GFS/NOAA, GEOS/GMAO, and GMI/GSFC, SHADOZ groups for data and simulations.